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Using ARCON96 for Control Room Radiological Habitability Assessments

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A. Introduction

Nuclear power plant licensees have recently shown an interest in updating their design-basis Control Room (CR) radiological habitability assessments. This interest primarily involves supporting implementation of the Alternative Source Term (Reference 1) for power uprate submittals as well as addressing the recently issued Generic Letter 2003-01 on Control Room Habitability (Reference 2).

Partially in response to this interest, the NRC has recently issued Regulatory Guide (RG) 1.194 (Reference 3) providing updated guidance on determining atmospheric dispersion factors (χ/Q values) in support of design basis CR radiological habitability assessments at nuclear power plants. Prior to RG 1.194, the NRC staff had never issued a regulatory guide providing guidance for generating CR χ/Q values. The primary CR atmospheric dispersion methodology previously used by the staff is documented in a CR habitability assessment procedure developed by Murphy and Campe (Reference 4) and its implementation is discussed in Section 6.4, "Control Room Habitability System" of NUREG-0800 (Reference 5).

One of the primary purposes of RG 1.194 is to provide guidance on the use of an updated methodology for generating CR χ/Q values, ARCON96 (Reference 6). ARCON96 is a relatively new computer code sponsored by the NRC which is based on a number of field studies conducted during the 1980s. It was developed, in part, to address industry's comments that the Murphy-Campe procedure was too conservative.

The ARCON96 computer code has been available for public distribution since mid-1997. Early NRC guidance on executing ARCON96 was provided in a July 1997 NRC letter to Westinghouse (Reference 7), during a February 2000 public meeting with NEI (Reference 8), and in the December 2001 draft of RG 1.194, DG-1111 (Reference 9). One of the most important aspects of these guidance documents, especially RG 1.194, is that the staff does not endorse all of the illustrative examples in the ARCON96 User's Guide (NUREG/CR-6331, Revision 1, Reference 6) as regulatory positions.

A number of licensees have used ARCON96 within the last couple of years in support of license submittals and the authors of this paper have had the opportunity to review these submitted analyses. From this review, it is clear that not all licensees understand the input requirements for ARCON96 as well as recognize the differences in guidance between the ARCON96 User's Guide and the staff positions stated in DG-1111 and, more recently, RG 1.194.

As such, the intent of this paper is to highlight some of the subtle aspects of the executing ARCON96 with regard to staff regulatory positions as well as identify some of the mistakes made by licensees in executing ARCON96.

DISCLAIMER: This paper was prepared by employees of the United States Nuclear Regulatory Commission. The NRC has neither approved nor disapproved its technical content.

B. Executing ARCON96

The following highlights those areas where RG 1.194 positions may differ from the examples provided in the ARCON96 User's Guide. These items are discussed in more detail in RG 1.194. The ARCON96 user is encouraged to refer to RG 1.194 for guidance in executing ARCON96 in support of any design basis accident licensing submittals.

1. Release Type: ARCON96 allows the user to select one of three different release configurations: ground, vent, or stack. The ARCON96 calculation of vent releases includes an algorithm to model "mixed-mode releases" as described in Regulatory Guide 1.111 (Reference 10), which addresses the methodologies applicable for determining χ/Q values for routine effluent releases. The mixed-mode release algorithm was based, in part, on limited field experiments and may not be sufficiently conservative for accident evaluations. For this reason, the vent release mode should not be used in design basis assessments. All releases analyzed within ARCON96 should be treated as either ground level releases or stack releases.

   Releases can be characterized as stack releases if the release is from a freestanding, vertical, uncapped stack that is either more than 2½ times the height of adjacent structures or is outside the directionally dependent zone of influence of adjacent structures. Any release not meeting these criteria should be classified as a ground level release. Details on defining the zone of influence of adjacent structures are provided in regulatory position 3.2.2. of RG 1.194.

2. Release Height: Although ARCON96 does not calculate plume rise from buoyancy or mechanical jet effects, plume rise can be calculated separately from the code and added to the physical height of the stack to obtain an effective release height. Plume rise may be considered for isolated, freestanding stacks and for vents located on plant buildings. In order to credit these adjustments, the buoyancy and/or vertical velocity of the plume should be maintained throughout the time intervals that the plume rise is credited.[1] Regulatory position 6 of RG 1.194 presents an appropriate set of plume rise equations.

3. Building Area: The ARCON96 User's Guide, NUREG/CR-6331, specifies that the building area value used to quantify building wake effects can range from 0 to 10,000 m^3. In reality, ARCON96 will not produce appropriate values if a building area value of zero is entered. Consequently, a value of 0.01 m^3 should be entered if a zero entry is desired.

4. Vertical Velocity: The vertical velocity only impacts stack releases. It is used to determine if the stack height should be reduced to account for plume downwash. Downwash is included in the calculation whenever the ratio of the vertical velocity to the release height wind speed is less than 1.5. If set to zero, the maximum downwash is calculated and the release height is reduced by an amount equal to six times the stack radius. An actual, non-zero vertical velocity should be used only if the vertical velocity of the release will be maintained during the course of the accident; otherwise, use zero.

5. Stack Flow: The stack flow impacts both ground level and stack releases. It is used to ensure that the near field concentrations are no greater than the concentration at the release point. This value is significant only if the flow is large and the distance from the release point to the receptor is small. An actual, non-zero stack flow should be used only if the stack flow will be maintained during the course of the accident; otherwise, use zero.

[1] Plume rise may not be used to demonstrate that a particular stack meets the 2½ times the adjacent structure height criterion in order to be classified as an elevated release.

6. Stack Radius: The stack radius only impacts stack releases. It is used to determine the stack height reduction during plume downwash conditions. An actual, non-zero stack radius should be used only if the stack flow is non-zero; otherwise, if the stack flow is zero, the stack radius should be set to zero.
7. Direction to Source: Use the direction from the receptor back to the release point. For example, if you stand at the receptor and are facing north as you look at the release point, enter 360° (north).

   Ensure the direction entered has the same point of reference as the wind directions reported in the meteorological data. For example, most wind direction systems are oriented to true north whereas the plant north shown on site plot drawings can be different from true north.
8. Surface Roughness: Surface roughness is used to adjust wind speeds to account for any difference between the meteorological instrumentation height and the release height. For most sites, use a value of 0.2 in lieu of the default value of 0.1. Reasonable values range from 0.1 for sites with low vegetation to 0.5 for forest-covered sites.
9. Averaging Sector Width Constant: The averaging sector width constant is used to prevent inconsistency between the centerline and sector average χ/Q values. Use a value of 4.3 in lieu of the default value of 4.0.
10. Vertical Area Sources: In order to qualify as a vertical area (or diffuse) source, the activity being released should be homogeneously distributed throughout the building and the release rate from the building surface should be reasonably constant over the surface of the building. Guidance for modeling vertical area sources includes the following:
    - The height and width of the area source (e.g., the building surface) are taken as the maximum vertical and horizontal dimensions of the above-grade building cross-sectional area perpendicular to the line of sight from the center of this area to the receptor.
    - The *distance to receptor* is defined by moving the vertical plane of this cross-sectional area forward along the line of sight until it intercepts the closest point on the building surface to the receptor.
    - The *direction to source* is defined as along the line of sight from the center of this cross-sectional area to the receptor.
    - The *initial diffusion coefficients* σ_y and σ_z are defined as one sixth of the cross-sectional area width and height, respectively.

    Refer to RG 1.194 for more specific guidance regarding modeling diffuse area source releases.

C. Experience from Reviewing ARCON96 Analyses

The authors have had an opportunity to review a number of recently submitted control room atmospheric dispersion analyses and have noticed the following issues:

1. Number of Meteorological Data Files Provided as Input: In one situation, six years of meteorological data were analyzed by executing ARCON96 six times, one time for each of the six years since each year resided on a separate file. An attempt was then made to average the resulting six sets of data. The licensee was unaware that all six data files could be included in one ARCON96 run.
2. Release Type: A release point was identified as a vent release instead of a ground level release.
3. Building Area: The containment building cross-sectional area was used for all release points when at least one release point was outside the zone of influence of the containment.
4. Wind Speed Units: In one situation, the wrong wind speed units were identified (e.g., the default setting of m/s was used instead of switching to the meteorological data base units of mph). In another situation,

the wind instrumentation was modified during the submitted period of record, resulting in some of the submitted wind data being reported in mph and the remaining data being reported in m/s.

5. Upper Wind Data: The ARCON96 User's Guide implies that providing a second level of wind data as input to the ARCON96 model is optional. If wind data are available for only a single measurement height, the ARCON96 User's Guide states that they should be entered in the lower measurement level fields of meteorological data file. However, if only one level of wind data is being provided as input to ARCON96, it is important that fields of 9s be entered in the upper level wind fields in the meteorological data files to indicate invalid data.[2]

6. Meteorological Data Quantity: The ARCON96 dispersion analyses should be based on five years of hourly observations with annual data recoverability of at least 90 percent,[3] although a shorter period of record may be accepted with sufficient justification. However, licensees have submitted meteorological data bases with extended instrument outages which have resulted in a data recovery rate of less than 90 percent.

7. Meteorological Data Quality: A copy of the ARCON96 meteorological input files should be provided as part of the licensing submittal. The staff will typically perform a review of the submitted data using the methodology described in NUREG-0917 (Reference 12) as well as spreadsheets. Some of the common data base problems that have been found which have generated requests for clarification (in the form of Requests for Additional Information or RAIs) include the following:

    - Occurrences of missing or duplicate hourly records.
    - Inconsistencies in the identification of invalid data (e.g., using values of zero instead of a field of 9's; note that zero is a valid wind speed value).
    - Occurrences of wind data remaining unchanged for several hours.
    - Occurrences of wind speed, wind direction, and/or stability classes frequency distributions (including calm winds) inconsistent from year to year.
    - Frequent occurrences of stable conditions during the day or unstable conditions at night.
    - Extended periods of extremely unstable (stability A) conditions.
    - Frequent occurrences of upper level wind speeds being less than the lower wind speeds.
    - Poor correlation between lower level and upper level wind direction frequency distributions (although this can sometimes be explained by the local topography).
    - Inconsistencies in the joint frequency distributions generated from the ARCON96 data as compared with those used as input to PAVAN (Reference 13) in the same licensing submittal.[4]

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[2] ARCON96 looks to use wind data listed in the upper level fields whenever the wind data in the lower level fields are missing. If these upper level wind fields are left blank, ARCON96 reads them as "zero" values. Zero is a valid wind speed value. As such, if the lower wind speed value is identified as invalid (9999), an upper wind speed value of 0 m/s will be used. This represents calm conditions, where the wind speed will be reassigned to the default minimum wind speed value (typically 0.5 m/s) and the receptor will be assumed to be directly downwind of the release point, regardless of the wind direction value. Note that calm conditions do not produce conservative χ/Q values in that the highest χ/Q values for ARCON96 typically occur during wind speeds of 3 to 4 m/s.

[3] The 90 percent data recovery criterion is from RG 1.23 (Reference 11).

[4] The PAVAN computer code is used to generate exclusion area boundary and low population zone χ/Q values for design-basis accident assessments.

8. Delta-Temperature Data Conversion to Stability Class: The conversion of the recorded delta-temperature data from °F/xyz ft to °C/100 m in order to classify stability class was done incorrectly. In addition, one licensee was unaware that their delta-temperature data were being recording as lower level minus upper level instead of the typical upper level minus lower level.
9. Wind Direction Range of Valid Values: The wind direction values provided as input to ARCON96 ranged from 0° to 359° instead of 1° to 360°. This results in some of the north wind observations being interpreted as invalid data.

Licensees are encouraged to spot check their ARCON96 data bases against the data in their original format to ensure the data conversion has been performed correctly.

D. Conclusion

The intent of this paper is to review some of the subtle aspects in executing ARCON96 to generate atmospheric dispersion analyses in support of design-basis CR radiological habitability assessments. Included are highlights of the differences between staff positions discussed in RG 1.194 and the examples given in the ARCON96 User's Guide. The authors hope that the issues discussed here will help licensees avoid common mistakes and improve the quality and acceptability of their submittals.

It should be noted that the guidance in RG 1.194 was developed after considerable effort by the staff, including resolution of public comments. Although alternative approaches may be proposed for consideration by the staff, licensees should be aware that significant deviations from the guidance may result in delays in obtaining staff approval.

E. References

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